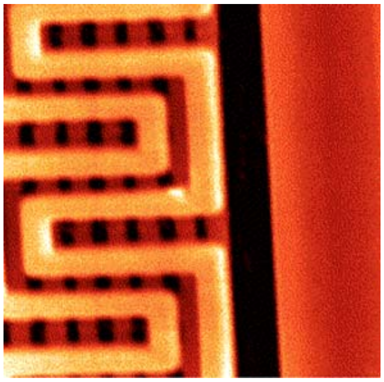
Nanosensors



Rachel Heil
12/7/07
Wentworth Institute of Technology
Department of Electronics and Mechanical
Professor Khabari Ph.D.

There are many advances in nanotechnology that if perfected could help make our world a safer and ultimately a better place to call home. The industry surrounding sensors is no exception. Nanosensors have been under research by many institutions for as long as ten years. A nanosensor is a sensor built on the atomic scale based in measurements of nanometers. There have been a number of advances in the research and development of nanosensors for a number of different applications. Some of the major applications are the medical field, national security, aerospace, integrated circuits, and many more. Along with many different applications for nanosensors, there are also many different types of nanosensors, and a number of ways to manufacture them. There are a number of challenges currently with the production of these nanosensors, however, when they become perfected for regular use they will have a number of advantages over the sensors that are used in today's technology.

A nanosensor is a sensor that is built on the nanoscale, whose purpose is mainly to obtain data on the atomic scale and transfer it into data that can be easily analyzed. These sensors can also be defined as "A chemical or physical sensor constructed using nanoscale components, usually microscopic or submicroscopic in size."(1) These sensors are ultra sensitive and can detect single virus particles or even ultra-low concentrations of a substance that could be potentially harmful. Since there is still so little known about this technology, it is difficult to put any single definition on what exactly a nanosensor is.

Nanosensors can be manufactured in a number of different methods. The three most commonly known methods are top-down lithography, bottom-up assembly, and molecular self-assembly. Researchers have also found a way to manufacture a nanosensor using semiconducting nanowires, which is said be an "easy-to-make" method of producing a type of nanosensor. Other methods of creating the sensors include the use of carbon nano tubes (CNTs), as well as one method using a material found in blue crabs.

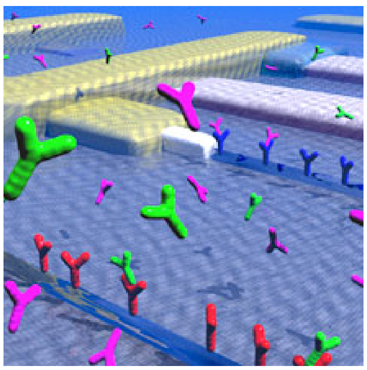
The top-down lithography method is quite simple in concept. Simply put it is the method of starting out with a larger block of material and carving out the desired form of what you want. The pieces that are carved out are used as the components to use in specific microelectronic systems such as sensors. In this case the components that are carved out are of the nanosized scale. This is the method that is used in the creation of many integrated circuits. In the case of nanosensors, it is common to use a silicon wafer as the base for this method. A layer of photoresist is then added to the wafer, then using lithography to shine a light on parts of the wafer to carve away parts of the wafer to create the component you desire. This piece of material can then be doped and modified using other materials to be used for things such as nanosensors.

The method of bottom-up assembly is a bit more difficult to accomplish, however, simple in concept. This method uses atomic sized components as the basis of the sensor. These components are moved one by one into position to create the sensor. This is an extremely difficult method to use especially in mass production because at this point in time it has only been achieved in a laboratory using atomic force microscopes. This process would most likely be used as a basis for the next method of manufacturing, called self-assembly.

There are two methods to the concept of molecular self-assembly, also known as “growing” nanostructures. The first of these methods uses a piece of previously created or even naturally formed nanostructure as the base and immersing it in free atoms of its own kind. Over time, the structure would begin to take a shape with an irregular surface that would then cause the structure to become more prone to attracting more molecules, continuing the pattern of capturing more of the free atoms and forming more of itself, creating a larger component of the nanosensor. The second method of self-assembly is more difficult. It begins with a complete set of components that automatically assemble themselves into the finished product, in this case the nanosensor. This has only been accomplished in the manufacturing of micro-sized computer chips, and has yet to be accomplished at the nanoscale. However, if this were to be perfected at the nanoscale, the sensors would be able to be made accurately, at a quicker rate and for a cheaper cost. This is because they would assemble themselves without having to manually assemble each individual sensor.

There are a few more specific sensors that have also been developed during the researching of nanosensors, which have their own special methods of manufacturing.

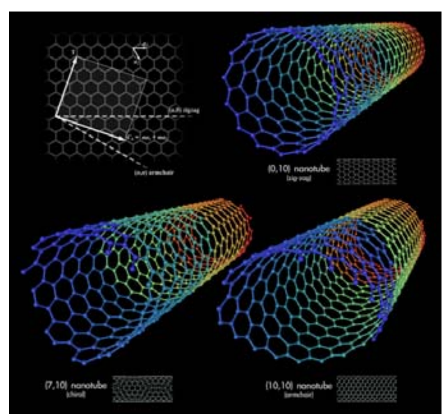
One of these specific sensors was created at Yale University. The creators of the sensor refer to it as an “easy-to-make” nanosensor. This sensor is based of on semiconducting nanowire technology. These sensors could be packed by the thousands into a hand-held device that could produce almost instantaneous results. The method used to create these sensors was actually quite simple, relatively speaking. They started with commercially available films of silicon on the top of an insulating material and then lay down patterns of lines known as masks. The masks determine the nanowires’ locations. The silicon not covered by the masks is then etched away, and since the masks are not thin enough to produce nanowires, the etching is allowed to continue eating away at the material under the edges of the mask. This process allowed the researchers to produce multiple nanosensors on the same chip. In the next step of the process, the nanowires are spotted with molecules that are designed to bind with the targeted antibody. When the target is in the presence of the sensor, it connects and causes the conductivity of the nanowire to change. This change in conductivity creates a signal that can be detected and analyzed. This sensor could potentially be used for early diagnoses of diseases such as cancer because the body's immune system produces a minute amount of antibodies in response to said diseases.



To the left:

An artists' concept of the nanowire sensors that are created by this "easy-to-make" method

Another method to creating nanosensors is by the use of carbon nanotubes, CNTs. This method can use either single or multi-walled CNTs. The CNTs are used as sensors by becoming functionalized at their ends and acting as biosensors to detect DNA or proteins. These are more appropriately referred to as biological probes for the nanosensors.

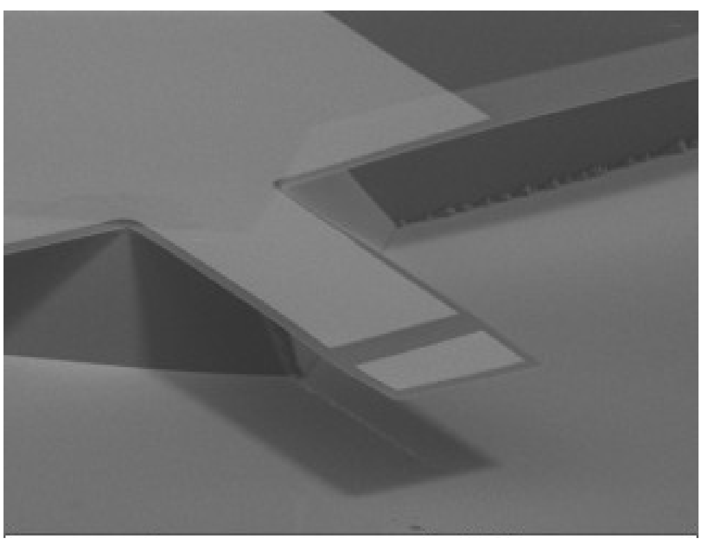


To the right:

Carbon nanotubes similar to those that could be used to function as nano-biosensor probes

One interesting type of sensor is something called a blue crab sensor. This is a sensor that has been developed by researchers at the University of Maryland. The reason it is called a blue crab sensor is because one of the key components of the sensor is a substance found in the blue crabs, specifically ones such as those found in Chesapeake Bay, as that is where the crabs used in the research originated. This substance is called chitosan, which is found in the shells of many crustaceans, not just blue crabs. This substance has some unique properties which make allow it to function as a component in these sensors. Chitosan is a biological compound which readily binds to negatively charged surfaces and can interact with a wide variety of substances. This is partly why it works well in complex and sensitive devices such as nanosensors. The sensors that were developed can be used to detect minute quantities of explosives, bioagents, chemicals, toxins, and other dangerous materials in the air and water.

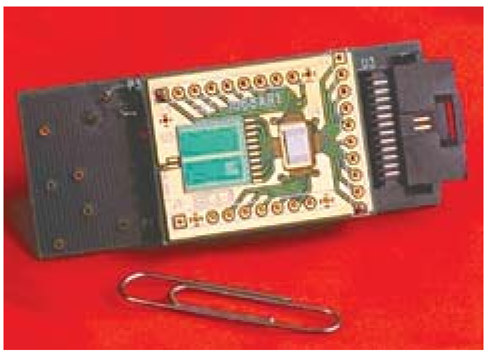
These blue crab sensors work using multiple mini vibrating cantilevers coated with the chitosan and an optical sensing technology that is used to see changes in the vibrations of the cantilevers. The cantilevers used in this sensor are similar to that of the



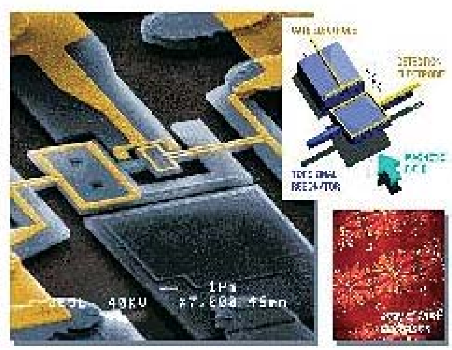
one shown in the image. The different cantilevers in the sensor can detect different substances and concentrations. When the targeted substance passes into the device from the air or the water, the chitosan that is on the cantilever interacts with it and causes the cantilever's vibration to change. The optical sensing system mentioned previously then sees the vibration change and makes an indication that the substance has been detected. A device such as this nanosensor could lead to many new developments in not only technology but also national security and safety in airports, hospitals, schools, and other major public places around the world.

There are many different types of nanosensors. A few of them are the chemical sensor, biosensors, electrometers, and deployable nanosensors.

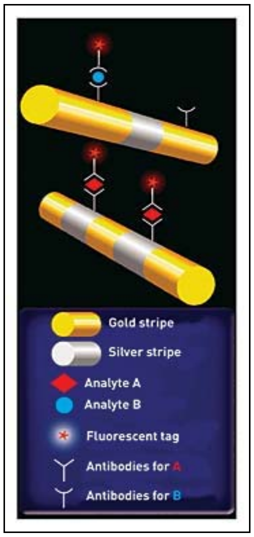
The chemical sensor uses capacitive readout cantilevers and electronics in order to analyze the signal. This type of sensor is sensitive enough to detect a single chemical or biological molecule. An image of a chemical sensor such as the one described is shown to the left.

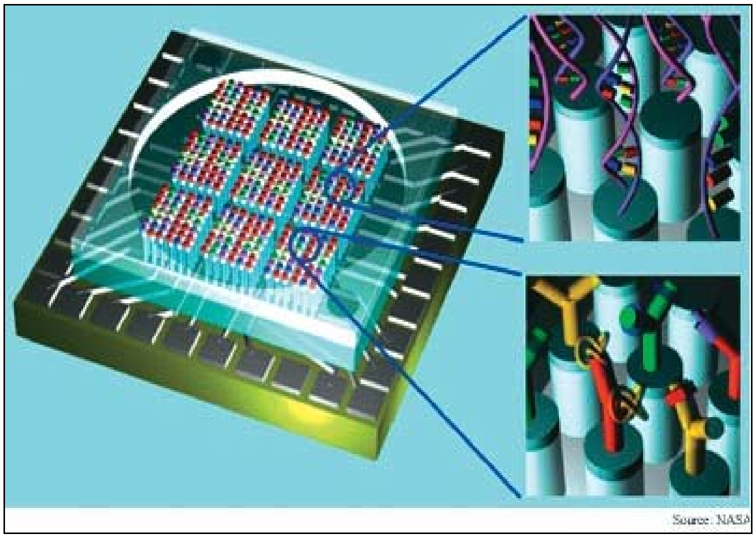


Another type of nanosensor is the electrometer which is a nanometer-scale mechanical electrometer that consists of a torsional mechanical resonator, a detection electrode, and a gate electrode which are used to couple charge to the mechanical element. The image to the right shows the electrometer with a schematic and micrographs of a single element and an array of elements.



One of the most largely funded areas of research in nanosensors is biosensors. This is mostly due to the possibilities that this technology could lead to in early cancer detection and detection of other various diseases. The biosensors can also be used to detect specific types of DNA. The image on the left shows Nanobarcode particles. They can be used in the sensing of DNA and other biomaterials using encoded antibodies on them. The image to the right is an example of carbon nanotubes being used as a biosensor, as was described earlier. The DNA molecules attach to the ends of the vertical carbon nanotubes that were grown on a silicon chip.

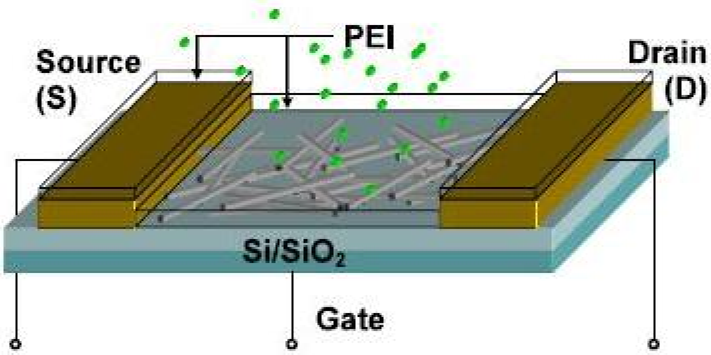




DNA detecting biosensors

Other types of biosensors can be used in more specific applications such as the detection of asthma attacks up to three weeks before it happens and assisting astronauts on space missions. These are just two major applications of nanosensors.

A nano-biosensor that can be used to detect asthma attacks up to three weeks before they happen just by using a handheld device to test the nitric oxide level in the patients breath. Testing regularly, as a diabetic patient would test their blood sugar level, could save lives. By knowing the nitric oxide level in their breath they could be alerted if the level were too high, or were increasing. This would indicate the risk of an asthma attack in the patient. The diagram below shows the most crucial pieces of the nanosensor that would accomplish this. The base of the sensor is a polymer coated nanotube field-



effect transistor (NTFET) containing a random network of single-walled carbon nanotubes between source and drain gold electrodes on a silicon oxide substrate.

Another biosensor is one that is being developed that could be used in the field of aeronautics. These nanosensors can pass through membranes and into the white blood cells called lymphocytes, in order to detect early radiation damage or infection in astronauts by sensing signs of biochemical changes. When on space missions, because of the amount of radiation, astronauts are at a higher risk of developing cancer due to cell damage. The sensors are created from synthetic polymers called dendrimers and are created layer-by-layer into spheres with a diameter of less than five nanometers. It is because of their small size that the goal of these sensors is to be able to administer them transdermally, through the skin. Being able to accomplish this and administer them every few weeks would avoid the need for injections or IVs during space missions. The development of these sensors would also eliminate the need to draw and test blood samples. This sensor would greatly improve conditions for astronauts going on space missions.

A different type of sensor is referred to as a deployable nanosensor. There is not a lot of research available on this type of nanosensor. These mostly refer to sensors that would be used in the military or other forms of national security. One sensor in particular is the SnifferSTAR, which is a nano-enabled chemical sensor that can be integrated into a micro unmanned aerial vehicle. This sensor is a lightweight, portable chemical detection system that combines a nanomaterial for sample collection and a concentration with a micro-electromechanical (MEM) based “chemical lab-on-a-chip” detector. An image of this sensor is shown to the left both in circuit form and in a field demonstration. This would likely be used in

homeland security and during times of war in which it could easily detect chemicals in the air without risking human lives by sending it up in the air instead.

There is an endless list of ways that nanosensors can be applied to our everyday lives for the simple reason that sensors are everywhere we look. In transportation you can see nanosensors being applied on land, at sea, as well as in the air and even in space as previously discussed. Also in the field of communications, nanosensors are likely to be seen in wired and wireless technologies as well as optical and RF technologies. They can even be seen in buildings and facilities, which consists of factories, offices, and even homes. Last but certainly not least, is perhaps the largest field aside from medical, which is robotics of all kinds.

As with everything there are always challenges that need to be faced and the field of nanosensors is no exception. Some of these are in the reduction of the cost of materials and devices and improving the reliability of them. Another challenge that is faced is in the actual packaging of them and putting them into a product that is useful for consumers. Perhaps one of the largest challenges with nanosensors is in the actual production of them. Mass production is difficult because the methods that are used to create the nanosensors are typically incompatible with those used in the making of the electronics that amplify and process the signals that the sensors generate. Also mass production is difficult for the simple reason that most nanosensors are still physically assembled by hand since finding a way to efficiently manufacture them in mass production is still being researched.

In the future we can see many of these advances become realities. Some of them may happen within the next five to ten years and some may not happen for fifty, or even within our lifetime. With the increasing research into this technology it is hard to tell. As far as nanosensors go, we can expect to see them start to pop up within our life time, even if we cannot go out to a store as consumers and purchase them. Some of the advantages that would come out of using nanosensors are because of their tiny size, the fact that they require less power to run, their greater sensitivity and that they have better specificity than today's sensors. All of these advantages will allow us to accomplish things that we could never imagine before such as atomic sized sensors flowing in our blood streams that could predict cancer and other diseases. Between the medical advancements that could be made with the use of nanosensors and the advancements in airborne chemical detection being used for national security, nanosensors could not only make our lives easier, but also safer in more than one way.

References:

General Information:

1. http://www.nanomedicine.com/NMI/Glossary.htm
2. http://www.sensorsmag.com/sensors/article/articleDetail.jsp?id=361237
3. http://www.technologyreview.com/Nanotech/18127/
4. http://en.wikipedia.org/wiki/Nanosensor

Biosensors:

5. http://blogs.zdnet.com/emergingtech/?p=672
6. http://www.lymphomation.org/biologics.htm

Blue Crab Nanosensors:

7. http://www.technologynewsdaily.com/node/3907
8. http://en.wikipedia.org/wiki/Chitosan
9. http://blogs.zdnet.com/emergingtech/?p=307

Aeronautics

10. http://www.sciencedaily.com/releases/2002/07/020711080818.htm

Other Sensors:

11. http://www.technologyreview.com/Nanotech/18127/